Prior Knowledge in chemistry instruction: Some insights from students' learning of ACIDS/BASES

Thomas, D.T. Sedumedi, PhD[1]

[1] Tshwane University of Technology, South Africa, Email. sedumeditdt@tut.ac.za

Abstract

The main purpose of teaching is to enhance learning by students. However, research has shown that teaching often has limited success in guiding students from their pre-instructional conceptual frameworks to new understandings. Therefore in order to improve or enhance learning, teachers would need to be clearer about the sort of understanding, knowledge and skills they want to develop with their students. This is only possible if teachers are aware of the ways in which students grapple with their own learning processes. That is, teachers need to understand students' prior knowledge and how it is used in knowledge construction during learning. This chapter raises three issues about prior knowledge: firstly it demonstrates the importance of prior knowledge on learning; secondly, it illuminates on the effects of the quality of prior knowledge on learning outcomes and lastly, it reports on the implications for the teaching of concepts in chemistry. To effectively assess the three issues about prior knowledge, an in-depth qualitative analysis of students' concepts and their use was conducted on three constructs of prior knowledge. The findings clearly demonstrate that if we are to improve students' learning in general and particularly in chemistry, far more attention should be paid on assessing the quality of the factors that influence the outcome(s) of their learning the most. Therefore, it is important to have a better understanding of students' prior knowledge before embarking upon teaching of new material.

Keywords*: Prior knowledge, chemistry instruction, ACIDS/BASES*

Introduction

Studies have been conducted on processes and relationships between and/or among the components of the teaching system in the fields of psychology and education. Components of the teaching system would in this chapter refer to *what* is taught, *how* it is taught, *who* is taught, *how* it is assessed and learned. In some of the studies (Ausubel, 1968; Biggs, 2003; Dochy, 1992; Resnick, 1989) the components of the teaching system were integrated while in others the foci were more specific to either. Completely separating the components of the teaching system is difficult because of their integrated nature. The goal of research on the teaching system has generally been to understand how humans learn and how better they can learn. However, recent studies on the teaching system have gone beyond just understanding learning. The content of what is learned and how it is learned has since become the target for research in many research studies. The focus on content has been influenced to some extent by differences in the nature of the content of subject matter.

The nature of subject matter has been found to affect the outcomes of learning in one way or the other. For example, studies in chemistry education (Gabel, 1999; Taber, 2002; Sirhan, 2007; Ware, 2001) have established that many students find chemistry to be among the subjects they find difficult to comprehend.

The concept of 'difficulty' can mean many things to many people and/or students considering the different backgrounds people bring into the learning situation. It is therefore necessary to explain the concept of 'difficulty' in the context of this chapter. Difficulty of subject matter in learning chemistry would therefore mean the inability by a student to construct understanding and/or generate meaning of concepts for meaningful learning. As this difficulty is not the same for all students it must therefore be due to a variety of factors. These factors affect learning differently for different subject matters and/or students. A host of factors have been identified as sources of difficulty in the learning chemistry. Sources of difficulties include the abstract nature of concepts (Johnstone, 1991b); language and communication (Gabel, 1999); and curriculum demands (De Vos, van Berkel & Verdonk, 1994). Johnstone attributes the abstract nature of concepts to the three levels (macro, sub-micro and symbolic) at which matter may be conceptualised as the main source of difficulty. Gabel cites the different meanings that English expressions (e.g. the use of reduction in electrochemistry have the opposite meaning as when used in English) have when used in chemistry. De Vos et al. posit that teachers do not follow appropriate strategies to promote conceptual understanding. These researchers attribute this to societal demands on the curriculum.

It is clear that the difficulty of learning in general and of learning chemistry in particular comes from a variety of factors. However what appears as common sources of difficulty in chemistry to many students are the nature and the manner in which it is usually taught. That is, the two factors are inherent in all teaching and learning (Gabel, 1999). The argument in this chapter is that among possible solutions to addressing the many factors contributing to the difficulty of learning is the understanding by both teachers and instructional designers of what the student already knows. What the student already knows is their prior knowledge of the subject matter of the topic to be taught. Students come into a learning situation with preconceived ideas of the learning matter. In fact, in his famous statement Ausubel (1968) argues that we need to ascertain what students know if we are to address their learning difficulties. That is, it is only through students' extant knowledge that appropriate diagnostic instruments and methods that teachers may understand what students already know or their prior knowledge.

The purpose in this chapter is therefore to demonstrate a framework that may be used to maximise the understanding of the quality or characteristics of students' prerequisite or prior knowledge in the learning situation. However, there are many characteristics of prior knowledge that may be assessed (Dochy & Alexander, 1995). In this chapter only two characteristics (structure and completeness) of students' prior knowledge will be assessed to determine the quality of students' prior knowledge within the three constructs (declarative, procedural and conditional) of their prior knowledge.

Chemistry Concepts: A view from the prior knowledge lens

It is generally accepted that to succeed in teaching one needs to understand the environment within which teaching and learning takes place. Teaching and learning environment includes the subject to be taught, available resources and the learner. That is, the teacher's plan should be based on the curriculum outcomes for the subject, the nature of the subject and the learner's knowledge. In fact, Magnusson, Krajcik and Borko (1999) find teaching to be "a highly complex cognitive activity" in which the teacher "must apply knowledge from multiple domains" if his or her teaching plan is to be successful (p.95). There are many factors contributing to the complexity of teaching. Common to these is the teacher's difficulty to establish what goes on in students' minds. In addition, different subjects require different teaching approaches and this is due to the nature of these subjects. Thus, the nature of the subject content adds to the complexity of effective teaching and/or meaningful learning of a particular subject.

In their independent studies, Gabel (1999), De Jong (2000) and Johnstone (1991b) reported that both teachers and students find chemistry a *difficult* subject to teach and learn respectively. The perceptions of teachers and students will obviously be different considering the fact that they emanate from opposite sides of the teaching-learning system. That is, the difficulty may be from different topics or different types and forms of subject matter. For example, Gabel (1999) attributes the difficulty of chemistry to the abstract nature of its concepts and the fact that they are inexplicably taught without the use of analogies or models. Furthermore these abstract chemistry concepts are central to further learning or understanding in chemistry and other sciences thus making students' advancement in these subjects difficult, or in some instances impossible (Taber, 2002; Sirhan, 2007). De Jong (2000) cites complaints students and teachers make about why they find chemistry teaching and learning difficult. For example students find chemical formulas difficult to comprehend. On the other hand teachers complain about making chemistry understandable to learners because repeated explanations and demonstrations tend to be ineffective.

According to Brown, Le May jr, Bursten and Murphy (2009) chemistry is the study of matter and the changes it undergoes. Therefore, in an attempt to illuminate more on the nature of chemistry as the source of teaching and learning difficulties, Johnstone (1991b) describes the nature of matter or its inherent features, qualities or characteristics. It is therefore important that we describe the nature of chemistry in order to understand how it may affect teaching and learning. Since chemistry is the study of matter, its properties and the changes matter undergoes, the nature of chemistry would therefore be embedded in its composition. Johnstone (1982) uses a triangle (**Figure 1**) to describe the three levels at which the teaching and learning of chemistry subject matter could be conceptualised.

With this representation, Johnstone (1982) demonstrates what Evans, Yaron and Leinhardt (2008) regard as the 'explanatory power' of chemistry. According to Evans et al. (2008) the explanatory power of chemistry is drawn from the sub-microscopic level but students generally observe and make measurements at macroscopic level. Therefore the different levels at which chemistry teaching and learning take place complicate both the learning and teaching processes (Johnstone, 2000). The *macroscopic* level describes what can be seen, touched and smelt; the *sub-microscopic* level, describes atoms, molecules, ions and structures of chemical compounds; and the *symbolic* or *representational* level, describes the symbols and equations (Johnstone, 2000).

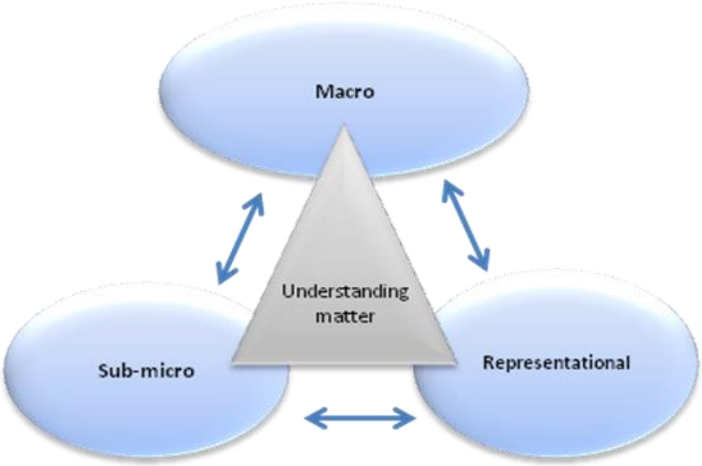

Figure 1: Levels of Conceptual Understanding of Matter in Chemistry (Johnstone, 2000)

The three levels are commonly seen as constituting the nature of chemistry. For example, the concept of *a proton* can be understood individually and interactively among the three conceptual levels. As a typical example of understanding a *proton* as a concept, it is represented as H^+ ion (*symbolic representation* and a *sub-micro* particle). At *macro* level, an aqueous acidic solution (according to the Brønsted theory of acids) is a solution that contains an excess of H^+ ions. What we need to ask in teaching is whether students are aware of these levels at which they are taught and/or learn chemistry. In fact, Harrison and

Treagust (2002), argue that understanding the particulate nature of matter is fundamental for both the students and their teachers in the teaching and/or learning of many topics in chemistry as it involves the particle theory. The two authors regard the particle theory as the basis of explanations of many topics (e.g. atomic structure, chemical equilibrium, and chemical reactions) in chemistry.

Clearly the nature of chemistry can play a fundamental part in understanding the problems associated with both the teaching and learning processes of chemistry. However, as earlier indicated in this discussion, teaching and learning are complex processes not only with regards to the activities involved between the teacher and the student. They are complex because of the different conceptions that teachers have about them. In fact, Norton, Richardson, Hartley, Newstead and Mayes (2005) argue that different approaches to teaching are a reflection of different underlying conceptions which change and are enhanced by acquisition of more sophisticated conceptions. The teachers' conception of teaching is therefore a typical example of the potential sources of problems in teaching and learning. There is therefore the need to reduce the complexity of teaching and learning either for the teacher or the student. The suggestion in this chapter is to focus on aspects of teaching and learning that we all can agree on. These aspects are the student, the knowledge they possess and the processes they undergo to acquire knowledge during teaching and learning.

Prior knowledge and Learning

One of the elusive quests by researchers has been the understanding of the processes of knowledge acquisition when individuals are engaged in learning (Bransford, Brown & Cocking, 2000). Understanding learning or its processes just like understanding teaching is complicated by the many perspectives in which it is generally understood. There are many ways in which learning is understood. For example, behaviourists (e.g. Pavlov, Watson, Thorndike, etc) assume learners to be passive recipients of knowledge from the teacher or responding to environmental stimuli. Furthermore (Santrock, 2001), behaviourists regard learning as involving a "relatively permanent change in behaviour that occurs through experience" (p.228). On the other hand cognitivists (e.g. Gagne, Wager, Bruner, etc) regard the human mind as an important and necessary 'tool' to understanding learning. That is, learning or knowledge acquisition is regarded as the outcome of symbolic mental constructions. Ormrod (2001) describes learning as a complex and multifaceted process that is based on behavioural change and mental associations. In effect the cognitivists' theory of learning expands on the behaviourists' theory by introducing the mental aspect. Cognitivists focus on mental processes underlying the individual's behavior.

The two theories are limited in their description of learning as they tend to isolate it from the learner's social and/or cultural environment backgrounds. Students come from different teaching and learning backgrounds. In South Africa for example these students come from disadvantaged science teaching backgrounds that have obviously influenced their learning in one way or the other. In fact, Vygotsky (as quoted in Carter, Westbrook & Thompkins, 1999) regards social contexts as paramount to the mediation of conceptual learning. In his argument through the *zone of proximal development* about the importance of social contexts, Vygotsky (as quoted in Moll, 1993) asserts that "maturing or developing mental functions must be fostered and assessed through collaborative, not independent or isolated activities". That is, individuals must be situated within specific social systems of interactions to enhance their learning or development (p.3).

Although it was clear from the behaviourist point of view what the student's role was (passive) in learning, this was not apparent in the cognitivists'. However, Wilson (1993) clarifies this with another dimension of learning namely; that the learning object has to engage in some kind of activity for learning to occur. That is, learning and knowledge are integral and inherent to everyday human activities as learning is a process of 'knowing'. Kolb (1984) further adds that learning is "the process whereby knowledge is created through transformation of experience" (p.21). To summarise Wilson's (1993) and Kolb's (1984) definitions and complement Santrock (2001) and Ormrod's (2001) definitions of learning and for a better understanding of students' learning, De Corte(2000) describes learning as "a constructive, cumulative, self-regulated, goal-oriented, situated, collaborative, and individually different process of knowledge building and meaning construction" (p.254).

In De Corte's (2000) definition of learning, four significant learning perspectives are emphasised. In addition to the perspectives already alluded to, two others, the differential and situative perspectives are apparent. The differential perspective (Pellegrino, Chudowsky & Glaser, 2001) emphasises the nature of individual differences in their knowledge and potential for learning whereas the situative perspective views learning in terms of practical activity and context (i.e. a person's learning is influenced by active engagement with others using tools and their language).The fact that learning involves transformation of one's experience (Kolb, 1984) supports the differential perspective in that individuals enter the learning situation with different knowledge bases and/or experiences, hence they have differing potential to learn. Bodner's (1986) contention that teaching does not necessarily result in learning concurs with situative perspective's emphasis on the important contribution made by practical engagement by the student and the role played by context in one's ability to learn. In the learning of chemistry concepts for example, the student learns as an individual or in collaboration with others through engaging in practical work activities. Although there has been many conflicting views as to whether practical work enhances learning (Hofstein & Lunetta, 1982); practical activities do have a high potential to mediate learning (Carter, Westbrook & Thompkins, 1999). In this chapter practical work is regarded as an integral part of scientific teaching and learning to support the notion that practical engagement promotes the active participation of students in their own learning as described in de Corte's (2000) description of learning.

It is apparent from the learning theories and/or views discussed that teaching and learning are indeed complex processes. There are many factors that influence the outcomes of both processes. However to avoid complicating the understanding of the relationship between students learning and their knowledge this discussion will be limited only to students learning of chemistry concepts and/or its conception on the acid-base topic. Therefore, the focus will be on how students learn or construct knowledge from their prior knowledge because the only outcome of teaching in all its forms and under any conditions is always knowledge. Woolfolk (1998) views knowledge as both the outcome of learning and as more than the end product of previous learning but also as guiding new knowledge. Greeno, Collins and Resnick (1996) describe this knowledge (prior knowledge) or its quality as important in determining the potential and extent of students' future learning. According to Dochy (1992) knowledge or prior knowledge can facilitate and/or impede learning. This therefore makes prior knowledge important in any teaching and learning system. For the purposes of this discussion this would be the knowledge that students bring and use in the learning situation.

How and what do students use knowledge for? There are as many views on what teaching is as there are on how knowledge acquisition occurs depending on various theories of learning. For example, constructivists view learning as a process of knowledge construction that involves motivation within a particular social context (Fosnot, 1996). Lennon (1997) posits that the constructed knowledge reflects the knowledge constructor's situation "at a certain historical moment in a given material and cultural context" (p. 37). Furthermore, De Corte (2000) in defining learning made reference to learning as a constructive process in which an individual actively builds knowledge and constructs meaning of his/her knowledge. However, in construction, one needs 'material' for the construction process. According to Resnick, (1989) current knowledge is learning the material the learning subject uses to construct knowledge. In fact, Glaser (1984) regards reasoning and learning as knowledge driven and that those with rich knowledge reason more profoundly and elaborate as they study and thereby learn more effectively.

Learning and more specifically chemistry learning involves the use of concepts. Concepts are building blocks of knowledge (Reif, 2008). According to Glynn and Duit (1995) scientific learning is a dynamic construction process involving *building, organising and elaborating* on knowledge of the natural phenomena through conceptual models. Conceptual models, which are cognitive representations of a real-world process, are important and, together with prior knowledge, are a prerequisite for a successful knowledge construction. Conceptual models cannot be built if there is no relevant and adequate prior knowledge for them to build on. Conceptual models are therefore the cornerstones of knowledge construction (Glynn & Duit, 1995). However this does not mean that students' mental models are necessarily valid. Students' mental models are products of their prior knowledge. Students' prior knowledge determines the quality of mental models students construct. Students' mental models are not always accurate representation of the scientifically valid conceptual understanding. For example, when a student was asked to describe the concept of *an aqueous acidic solution* the student responded by indicating that it was "a solution with a high concentration of H^+ ions". An *aqueous acidic solution* is a solution with H^+ ions concentration exceeding OH^- ions concentration in this solution. The H^+ ion concentration may be high but if it is less than that of the OH^- that solution will not be acidic. What then is the difference between conceptual models and mental models?

Barquero (1995) describes a mental model, within the teaching context as "a type of knowledge representation which is implicit, incomplete, imprecise, incoherent with normative knowledge in various domains, but it is a useful one, since it results in a powerful explicative and predictive tool for the interaction of subjects with the world, and a dependable source of knowledge, for it comes from the subjects' own perceptive and manipulative experience with this world" (p.12). Conceptual models on the other hand are (Greca & Moreira, 2000) "precise and complete representations that are coherent with scientifically accepted knowledge… shared by a given community, and have their coherence with the scientific knowledge of that community" (p.5). The difference between these models (**Figure 2**) can be attributed to students' different interpretations of learning material as a result of the quality of their prior knowledge. Ideally, a conceptual model and a mental model should be identical. The quality of prior knowledge determines the degree to which the student's mental model corresponds to the scientifically valid conceptual models learned (Glynn & Duit, 1995).

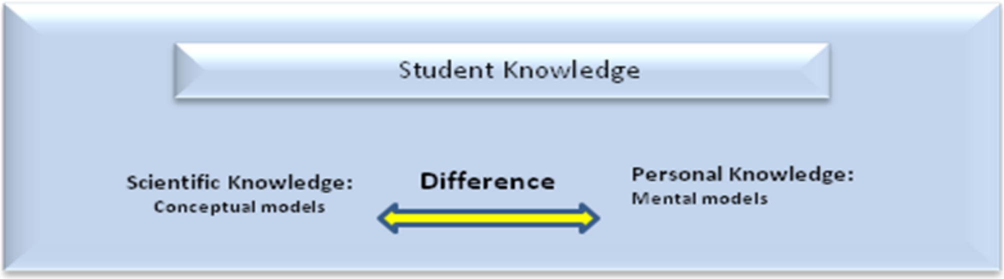

Figure 2: Students' personal mental models and/or scientifically valid conceptual models (Adapted from Glynn & Duit, 1995)

Students use their mental model to explain and make predictions about the object of learning represented by it. The mental model has to be functional to the student who constructs it (Greca & Moreira, 2000). Understanding conceptual and mental models during knowledge construction can be an effective tool for both the teacher and student to apply and enhance teaching and learning respectively. The teacher may use conceptual models to bridge the gap that exists between conceptual models (i.e. external representation created by researchers, teachers, etc) and the students' mental models during teaching and learning. The student may use the gap to reflect on his or her limitations in understanding a concept. Therefore prior assessment of prior knowledge is important in any teaching and learning situation. It is also important to know exactly what is it that we will be assessing.

Dochy and Alexander (1995) describe prior knowledge as (1) dynamic in nature; (2) available before a certain task; (3) structured; (4) existing in multiple states (e.g. as declarative, procedural and conditional knowledge); (5) explicit and tacit in nature and (6) containing conceptual and metacognitive components. Although these characteristics simplify the understanding of prior knowledge; they do not explain the dynamics of the individual student's prior knowledge or the interactive nature of knowledge. Of greater interest in Dochy and Alexander's (1995) characterization of prior knowledge and relevance in the context of this chapter is the demarcation of prior knowledge into three related interactive knowledge constructs. The three prior knowledge constructs are meant to simplify the understanding of the interactive nature of prior knowledge as it is easier to specify the type of knowledge to focus on in the student's knowledge base for analytical purposes. For instance,

- *Declarative knowledge* describes the knowledge of vocabulary terms and facts. A vocabulary term refers to a word or phrase about which one has 'accurate' but not necessarily a deep level of understanding. Facts on the other hand present information about specific things and events (Marzano & Kendall, 2007).
- *Procedural knowledge* describes the individual's ability to do various procedures necessary to complete some task (Shuell, 1985), and
- *Conditional knowledge* is the understanding of when and where declarative and procedural knowledge are applicable respectively (Alexander, Schallert & Hare, 1991).

Hence the individual's knowledge of any subject matter including chemistry may be described in terms of what and how much of the three types of knowledge the individual possesses (Marzano & Kendall, 2007). It is therefore partly through these three constructs and their interactive nature that an attempt will be made to demonstrate how the quality of students' prior knowledge influences the outcomes of learning of acid-base concepts. Finally, in his response to how students' difficulties in learning in general and in science in particular may be overcome, Biggs (2003) suggests that we reflect on the way we teach by basing our thinking on what we know about how students learn. Hence we need to link students' prior knowledge and our instructional approaches since the knowledge they construct is to a large extent influenced by their prior knowledge (Ausubel, 1968) and the way we teach.

Method

Research Design

The outcome of any research study is mostly determined by the appropriateness of the methods and instruments used. That is, the methods that one uses will determine the validity and/or reliability of the study. This chapter is based on a larger composite case study conducted through qualitative methods. The choice of the qualitative approach was based on the need for an in-depth understanding of the students' concepts and their prior knowledge in the learning processes. According to Denzin and Lincoln (2003) qualitative methods have the potential to study things in their natural settings and to make sense of or to interpret phenomena in terms of the meanings people bring to them. In the study reported in this chapter the natural setting was the learning environment of science (which included a chemistry laboratory) for students studying towards a specialist course for chemical laboratory technicians. In addition, the natural setting includes students with diverse knowledge or experiences of science. This is the knowledge and/or experiences that need understanding from the teacher's perspective.

Research Context

The study reported in this chapter was conducted at a South African university of technology. The university draws most of its student population from disadvantaged science teaching and learning backgrounds. A disadvantaged science teaching and learning background refers to a background where students learn science with limited physical (e.g. laboratories, libraries) and human resources (e.g. under qualified teachers for specific subjects). The students from whom data was collected were in their first-year of study towards a Diploma in Analytical Chemistry. This is a specialist qualification for chemical laboratory technicians.

The rationale for the study was therefore based on the assumption that the students from such backgrounds may not be ready to cope with the learning content required at university considering the quality of concepts and/ or prior knowledge they bring along. According to Ferrari and Elik (2003) concepts are "internal representations…that are the vehicles for thought in the mind or brain" (p.24). That is, they mediate in knowledge construction (Reif, 2008). Therefore, understanding students' meaning and use of concepts in learning should be a priority for the teacher. The students' meaning and use of concepts reflect the quality of their prior knowledge. The insights reported in this chapter are therefore meant to demonstrate the importance of concepts as building blocks of knowledge or their influence in students' learning outcomes. That is, this report focuses on how the structure and completeness (quality) of concepts determines the learning outcomes in a teaching and learning situation.

Procedures

Studying concepts (prior knowledge) and their use is generally made difficult by the nature of knowledge. According to Dochy and Alexander (1995) prior knowledge is pervasive and difficult to study. In fact, the two researchers consider concepts to be dynamic as they change with time when students are exposed to more information that may alter their knowledge in the process of a study. The continuous change in knowledge requires an environment that will minimise the effect of this change when studying concepts. The report in this chapter focuses on only two and related factors that characterize concepts or knowledge in the learning process. The two factors are the *structure* and *completeness* of prior knowledge. Structure of quality knowledge here would refer to when components or elements of prior knowledge are well organised, coherent and make sense (Dochy, 1992). Completeness of knowledge on the other hand (Dochy, 1992) would refer to when parts of prior knowledge especially in use are correct or valid, complete and unambiguous. These factors are important as far as construction of quality knowledge is concerned. The components or elements refer to the concepts that Reif (2008) earlier referred to as building blocks of knowledge. Both structure and completeness are continuously changing as the student is exposed to more information because prior knowledge is dynamic (Dochy & Alexander, 1995).

The timing and choice of methods for data collection was therefore of paramount importance considering the dynamic nature of knowledge in the study. For example students had to write PKDT before they could do practical work and/or be interviewed. The two latter processes were meant to be reflective of the knowledge established through the PKDT. This test was used to estimate or approximate students' prior knowledge as it is not possible to determine all knowledge from students' knowledge bases. It was important to first establish students' prior knowledge relevant to the acid-base topic. Students were further subjected to practical work activities and observed and/or interviewed (O&I) where understanding of their use of concepts could be demonstrated in practice. Students engaged in practical work in dyads to promote *social collaboration*. According to Tobin (1990) social collaboration in practical activities enables understanding to be clarified, elaborated and evaluated between partners. Collaboration ensured collection of information as it was possible to record the discussion between both members of the dyad and infer some meanings from their actions as they manipulated the apparatus. Information collected from the PKDT was used for benchmarking and to inform some of the questions posed as students engaged in their work. The assumption here was that students' actions in practice would to a large extent reflect the meanings they attach to concepts responsible for their knowledge. Furthermore students had to compile a written practical work report. The report was used as an additional source of information on students' understanding and use of concepts in the process of learning.

Information collected from the sources indicated, was to establish specific elements of the text, concepts, meanings, thoughts and interpretations as presented by individual students. The analysis was conducted through a framework (**Figure 3**) that includes constructs of prior knowledge (i.e. declarative, procedural and conditional knowledge) of the acid-base topic.

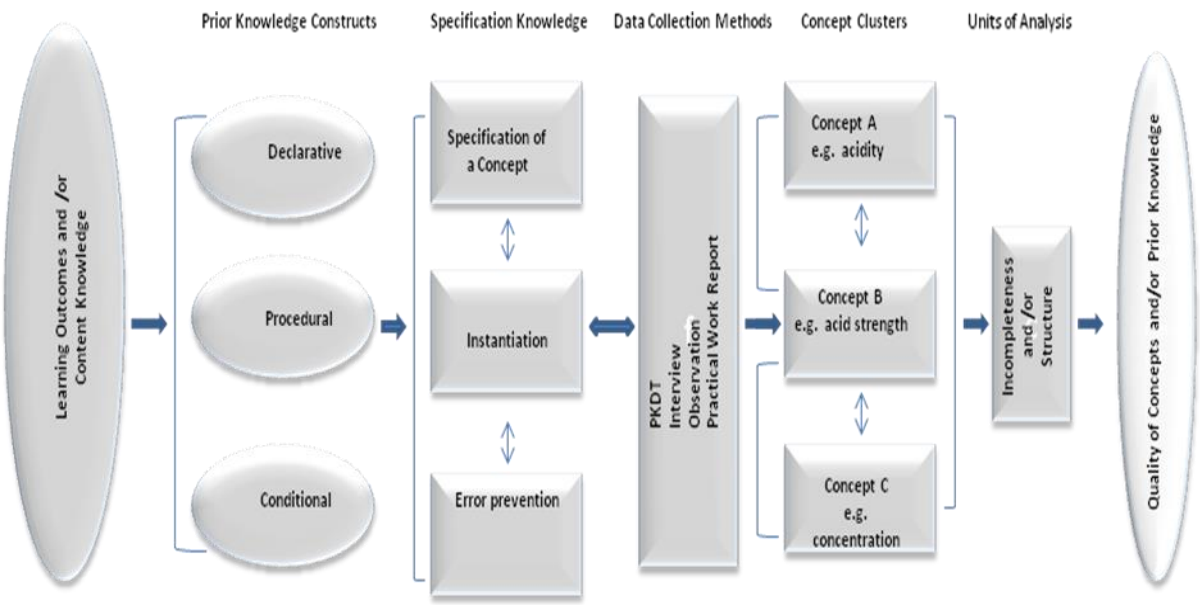

Figure 3: Framework for the analysis of quality of concepts and/or use of prior knowledge

The three constructs were meant to reveal the ability to *specify a concept* (declarative knowledge); *instantiate* knowledge (procedural knowledge) constructed from concepts and *reflect* on knowledge already in place and/or *prevent errors* (conditional knowledge) from one's knowledge. The framework was used to guide and ensure that the analysis was specific to a particular prior knowledge construct of a concept or its use. That is, the focus was on the analysis of the understanding of concepts or their meanings through usage and the potential effect the knowledge may have had on the outcomes of learning. In other words the analysis was aimed at establishing the quality of prior knowledge in terms of its structure and completeness.

Information obtained from different sources or instruments was chunked into categories or concept clusters that were deemed to contain the student's most basic knowledge required to interpret scientific concepts fully without committing errors of interpretation. The chunking process was done on different concepts for different participating students. However, not all sources of information contributed equally to the construction of a concept cluster. Information drawn from a source must however provide information representative of and useful enough to construct meanings or thoughts from students' prior knowledge.

The process of data analysis to generate meanings from data within and across concept clusters was based on Graesser, Singer and Trabasso's (1994) *search after meaning principle.* According to this principle:

- meaning that represents goals at deep levels of representation is constructed;
- a meaning that is coherent at both local (within a concept cluster e.g. acidity) and global (across concept clusters e.g. acidity and acid strength) levels is constructed. Coherence at local level refers to structures and processes that organise elements and constituents and referents of adjacent clauses or short sequences of clauses. At global level, coherence is established when local chunks of information are organised and interrelated into higher order chunks; and

- Actions, events mentioned (or inferred from practical work activities) in the text (of responses to questions) are explained.

The use of this principle made the analytical process more specific to different constructs of students' prior knowledge. That is, it was possible to focus on specific elements of the text of responses on certain concepts, thoughts, language and interpretations as presented by students. In addition, it was possible to analyse students' concepts and use of knowledge at the three constructs (declarative, procedural and conditional) of prior knowledge and three levels (macro, micro and symbolic) of conceptualisation of matter.

In the process of analysis it was important to ensure where it was appropriate and possible, to focus on the three constructs individually and/or their relationship. Analysis within the declarative construct focused on students' ability to specify concepts. This meant that students had to specify concepts according to explicit rules and to ensure that they are unambiguously identified, leading to clearly interpretable scientific knowledge (Reif, 1985). Describing a concept is not a guarantee that one has an understanding of that concept. That is, describing a concept does not make it usable in practice (Reif, 1985).

Ability to apply or instantiate a concept was the focus of analysis within the procedural construct of prior knowledge. This is where a student demonstrates a variety of ways to use his/her knowledge to identify and use the concept in various possible symbolic representations (Reif, 1985). Finally, it was also important to assess knowledge as it is reflected upon. This is a demonstration that students can prevent or avoid likely errors.

Results

The results provided in this chapter are for only one of the cases used in the larger study. The results are reported in a concept cluster for particular concepts and/or their usage. A concept cluster is a chunk of data collected from different sources with the aim of constructing students' understanding of concepts or their use. The concepts of interest in this chapter were drawn from an acid-base topic where these concepts were applied in a titration process. The titration process was used to capture both the theoretical and practical application of concepts on a topic of acids and bases.

Concept Cluster

Teacher: Q.1 Presume that you are titrating a weak acid (CH_3COOH) and a strong base (NaOH). What would the expression *equivalence point* mean in this process? (**PKDT**).

Student: *It will mean that the amount of added strong acid is equivalent to the base.*

Teacher: Q.2 What do you understand by the term *endpoint* in a titration process? (**O&I**)

Student: *It indicates physical change.*

Teacher: Q.3. Differentiate between *equivalence* point and *endpoint* in a titration process? (**O&I**)

Student: *Equivalence point indicates that amount of added standard reagent is equal to analyte*

Teacher: Q.4. Which one between *equivalence* point and *endpoint* in a titration process occurs first? (O&I)

Student: *Endpoint*

Teacher: Q.5 Why do you think *endpoint* comes before *equivalence* point?

Student: *Endpoint means after everything has happened...hmmm... No sir...this one is confusing. I am sticking to my first answer. Maybe I understand the meaning...I do not know what happens.* **(After a while):** *hmm...I think it is equivalence point...before we see any changes (in colour).*

Snippets from the student's practical work report

Method

- ***10 cm^3*** *of vinegar solution was transferred into a* ***100 cm^3*** *volumetric flask with a pipette with distilled water up to the mark.*
- ***25cm^3*** *of vinegar was transferred into 2 conical flasks using a pipette.*
- *Three drops of phenolphthalein were added...*
- ***NaOH*** *was then titrated...until the endpoint was reached.*

Calculations (sourced from a concept cluster for a different concept)

Teacher: **Q.6** Is it possible to weigh vinegar in liquid form? (**O&I**)
Student: *Yes...but you must have a solid.*
Teacher: **Q.7** How would you determine the mass of the liquid vinegar solution? (O&I)
Student: *By using the density.*
Teacher: **Q.8** Show calculations to determine the % content of CH_3COOH in the vinegar solution given the density (1, 045 g/cm^3) of the vinegar solution to be and molecular mass (36, 45 g.mol^{-1}) of acetic acid. (PWR)
Student: $D = {}^{m}/_{v}$
mass = 1.045 g/cm^3x 22.7 = 23.72
$\% \ CH_3COOH = \frac{23.72}{25} \times 100 = 98.88\%$
Teacher: **Q.9** Differentiate between a **dilute** solution of a **weak** acid and a concentrated solution of a weak acid. Illustrate your response with a relevant example (s). (**PKDT**)
Student: *Dilute solution of a weak acid: A solution which dissolves completely is a weak acid:*
$CH_3COOH \rightleftharpoons CH_3COO^- + H^+$. *Concentrated = that ionised partly:* $NH_4 \rightarrow NH_3 + H_3O^+$.

NB: The questions (Teacher) and responses (Student) in the concept cluster are not arranged in any particular sequence.

The cluster constructed may not necessarily represent the whole of the student's knowledge or information from which her understanding of the concepts could be interpreted. However, the information in the cluster is sufficient to be used to interpret the student's basic understanding of the concepts. That is, the concept cluster is an estimation of the basic information that could be abstracted from the students' knowledge base to represent her conceptual structure about her understanding of the concepts indicated and their application. The information collected in the clusters is aimed to reflect the student's knowledge within and across the three constructs of prior knowledge at the three levels (macro, sub-micro and symbolic) at which matter may be conceptualised (**Figure 1**).

Findings and Discussion

During learning, concepts are represented from the processing of information from different perceptual systems (Hampton & Moss, 2003). That is, students represent their concepts according to their prior knowledge. In fact, students are sources of concepts and intentional conceptual change as they progressively construct understanding of learning material (Ferrari & Elik, 2000). This chapter is a report of a student's concepts (or their construction) and their use in a chemistry learning environment that includes a chemistry laboratory. The focus of this discussion is the *structure of the student's knowledge*, its *completeness* and *effect* on the outcome of learning. The description and interpretation of the student's knowledge will therefore be within the most basic knowledge required to interpret a scientific concept fully and unambiguously. That is, the description will be within Reif's (1985) *specification knowledge* and focus on concepts that students generally confuse their meanings and usage. Specification knowledge as described earlier in this chapter constitutes specification *of concept*, its *instantiation* and *error prevention* (**Figure 3**).

Specification of a concept

Specification of a concept demonstrates one's ability to unambiguously define or describe it. It does not always indicate that one understands the concept. Ideally, the responses and the observation reported in the concept cluster should indicate or reflect the students' understanding of a concept according to the specified rules. The discussion within this part of the specification knowledge describes how this student describes, understands and use identified concepts.

The student's response to Q.1 and Q.3 demonstrates that the concepts *equivalent* and *equal* are used as synonyms. In the case of a 1:1 reaction in a titration this understanding will not have a bearing on the usage of these concepts as synonyms. However, in reactions where reaction ratios are not 1:1 the understanding will result in an incorrect usage. For example in a reaction of sodium hydroxide (NaOH) and sulphuric acid (H_2SO_4) the reacting moles will not necessarily be equal but equivalent. For amounts of different reacting substances to be *equivalent* and/or *equal* depends on their stoichiometric relationships. For example when a 0.5 M solution of NaOH reacts with a solution of HCl of the same concentration they react in a ratio of 1:1 therefore the amounts (in *ml* or in *moles*) that react for the two solutions to result in a neutral solution are equal. The same cannot be said when HCl is replaced with H_2SO_4 because of the ratio (2:1) in which NaOH reacts with H_2SO_4. From the student's response it is apparent that she confuses the two terms in the context of chemical reactions in a titration process. She can therefore not identify the concept of equivalence unambiguously. Finally, in her specification of the concept 'endpoint" (Q.2) the student does not describe the concept. Instead, she only indicates how the endpoint is indicated. Even the colour change she is referring to reflects a chemical change (i.e. the reaction between the indicator and the reactant in excess (or over titrated reactant) in a titration.

Instantiation

With the kind of descriptions of equivalence and endpoint the student provided will she be able to use them? Does the student 'see' beyond the physical change (colour change) of the indicator? In her response to Q.2 the student only indicates what happens in the reaction vessel when endpoint is reached. Endpoint is the point during titration at which reacting species are generally thought to have equivalent amounts according to the reaction ratio at which they combine. The student does not differentiate between the two concepts but only defines equivalence point. In fact, one can only differentiate objects or things if she is able to describe them fully and unambiguously. Earlier responses from the concept cluster to what equivalence point and endpoint suggest that the student may find it difficult to provide a valid and unambiguous response to Q.3. There is no indication in her responses of what could be happening inside the titration vessel. That is the student does not seem to "see' beyond the macro level of matter (Figure 1). This view is supported by her response to Q.4. Finally the confusion and uncertainty that prevails in her attempt to respond to Q.5 clearly demonstrates that her chemistry knowledge is mostly conceived at the macro level as far as the nature of matter is concerned.

Error prevention

It is unthinkable that errors can be prevented without adequate, well structured and relevant knowledge to do so. That is, we need to use this knowledge to reflect on what we do and how we do it. In other words, the quality of this knowledge determines the extent to which errors may be prevented. This knowledge is use to distinguish between valid or invalid information and facts. In the case of the concept cluster constructed for this student on the equivalence point and endpoint, her knowledge of these concepts is not entirely convincing that it is adequate and well structured to prevent errors. Clearly the student's response in Q.5 highlights the dynamic, fluid and interactive nature of knowledge. At this point the student eventually managed to construct some understanding of when each of the two concepts is arrived at or indicated in a titration process. Finally her knowledge of the two concepts as demonstrated by her responses appears incomplete and incoherent to assist her in reflecting on errors.

Another indication of the general quality of the student's knowledge is apparent in her understanding of the concepts expressing amounts of substances. For example the student confuses acid concentration and acid strength. It is clear in her concept description (Q.9) of a dilute acid and a weak acid that the student's conception of the two concepts is invalid. Her examples of the response confirm clearly that she is confusing description of a dilute acid solution with that of a weak acid solution. In conclusion on the student's understanding of the dilute (concentration) and weak (strength) concepts in the topic of acids and bases, it is apparent that it would be difficult to apply the concepts in different contexts.

The amount (% concentration) of acetic acid estimated in the sample of vinegar was 4 to 6 %. This estimation was provided in the experimental procedure to students during a practical work activity. In her final calculation the percentage acetic acid in vinegar was 94.88 %. This clearly indicates that the description or the confusion with her description might have had an effect on how to handle the relationship of components of the equation (D = m/v) in the calculations. In fact in her final answer despite the hint (4-6%) of the estimated concentration, the student continued to reflect it as 98.44% an amount that is far more concentrated than the estimated figure. This clearly demonstrates lack of reflection on her knowledge or the provided information. The analysis outcomes on students' knowledge highlights some insights into the quality of students' knowledge in terms of its effect in *facilitating* and/or *inhibiting* (Dochy, 1992) learning.

The discussion on the *confusion* nature among some concepts clearly highlights the importance of diagnosis of students' knowledge. In addition, it also highlights the extent and the type of knowledge that should be assessed at any particular stage of learning. In the case of this student it is clear that the three stage (declarative, procedural and conditional) assessment was important as it helped in accessing not only her knowledge of concepts but also her confusion of the chemistry and English languages were brought to the fore. Therefore in reporting about the structure of knowledge and its completeness, the effect of the interaction of the chemistry and English languages will feature prominently.

The structure of knowledge is assessed in terms of coherence between and/or among concepts and their use within the three constructs of prior knowledge. This does not in any way suggest or imply that if one cannot describe a concept accurately and unambiguously his/her ability to practically engage in a related procedure may be inhibited. Students do engage in solving problems algorithmically without a theoretical understanding of related concepts. There are however certain learning activities that need conceptual understanding of some concepts if new learning is to be enhanced as was apparent in the concept cluster responses of this student.

The completeness is assessed in terms of missing elements in the student's knowledge base when the knowledge is declared, applied or reflected on. For example in her calculation of the percent concentration the student's knowledge was incomplete as far as the application of the equation density = m/v and her conception of a dilute, concentrated and strong acids are concerned. The quality of this student's knowledge here echoes Dochy's (1992) contention that for one's prior knowledge to be effective in learning it must have certain qualities such as reasonableness, completeness and correctness. In fact he adds that it must also be available and well structured.

Generally the findings according to the framework used in the analysis can be summarised in three main findings. The findings are based on three constructs of prior knowledge and their interrelationships. In addition, the macroscopic, microscopic and symbolic representation of chemistry (nature of chemistry) is used to assess and describe the student's concepts and use of knowledge:

Firstly, it was apparent that the student's description of concepts was in some instances inadequate. That is, the descriptions were mostly at the macroscopic level of conceptualisation of matter. For example what transpired in a reaction vessel was only identified as colour change without elaboration of what that meant. The student did not use the particulate nature of matter at the microscopic level where the chemical process was unfolding to describe this colour change. This could be an indication of the level at which students are generally taught.

The second finding was on the use of the concepts as understood. The student's knowledge on applying the understanding of concepts was apparent in the uncertainty of what each of them meant during practical work. For example *equivalence point and/or endpoint* were difficult to differentiate as to when each came first during a titration. Although the student finally made her mind on further probing, it was initially clear that she was uncertain about the two concepts.

Finally, the incomplete and poorly structured or organised knowledge of the student seemed to affect her reflective capabilities in using her earlier demonstrated although not so convincing knowledge of some of the concepts such as the relationship between density (D), mass (m) and volume (v). In her calculation of percent acetic acid in vinegar she used the incorrect volume. That is, instead of using the volume of the sample of vinegar to determine the mass of the sample the student used the volume of the standard solution. Here the equation was relevant but substitutions were incorrectly made. The 94.88% should have prompted the student to rethink her approach since the percent was far too high as compared to the estimated 4 to 6% indicated in the experimental procedure. In this case the student could not prevent errors in her calculations.

Conclusions

Clearly there is no simple description of something as complex as knowledge. Earlier in this discussion the pervasive nature of knowledge was mentioned as a factor that contributes to the difficulty of studying knowledge. Reporting about its structure or completeness in this chapter was posing such a challenge. That is, the findings on concepts could not be reported in isolation from their use as there was a need in some instances to infer meaning of what the student understood. There is therefore a need as illustrated earlier in this chapter to develop an integrated relational reporting structure of knowledge both during and after the learning process. Assessing knowledge as isolated concepts defeats the goal of enhancing transferrable knowledge among students.

Knowledge is interactive, dynamic and fluid in nature and should at all times be treated as such (Dochy & Alexander, 1995).

Thus reporting knowledge within a particular structure simplifies our understanding of what the student knows and how the student's knowledge might be used to inform our teaching. In this chapter the structure and completeness of knowledge were reported according to the framework for analysis (Figure 3).

Clearly the analysis framework offered an opportunity to provide a better understanding of the quality of the students' knowledge. More information, including information about the language aspect of the student's knowledge base was highlighted through the analysis process. In conclusion assessment of student's prior knowledge before any teaching of a topic can benefit teaching in many ways.

Implications for Teaching and Learning

There are many teaching and learning lessons and/or implications that can be learned and/or drawn from this chapter. These lessons can be divided into two categories. One being lessons for teachers and/or teaching and the second being lessons for students. Lessons for teachers are on the understanding of the students and the nature of the subject matter. For students it is important that they understand what they know and how they know it if they are to engage meaningfully in the construction of their knowledge.

What does it mean for teachers to understand the students and the nature of the subject matter? Understanding students in learning means the teacher has access to their conceptions and reasoning strategies as they construct understanding or generate meanings of concepts. This puts the teacher at an advantage position to present new information at an appropriate time and level of the students' extant knowledge (Treagust, Chittleborough & Mamiala, 2003). That is, it guides the teacher's teaching sequence. The chapter encourages an in-depth assessment of students' knowledge before any teaching of a topic could be embarked upon.

Finally, the teacher's deep understanding of the student's knowledge is at the same time an opportunity for the student to understand his/her knowledge better. Obviously when the teacher who understands the student's knowledge at the level as described, will at the same time teach at the same level to his/her students. It is at this level where students will be made aware of the quality of their knowledge. Being aware of one's knowledge enhances the chance for self-reflection and consequently for self-motivation to improve one's knowledge through meaningful learning.

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